

How to use the MINOS near detector  
(or any other MINOS-like detector)  
to estimate the  $\nu_e$  component at  
an arbitrary far detector location

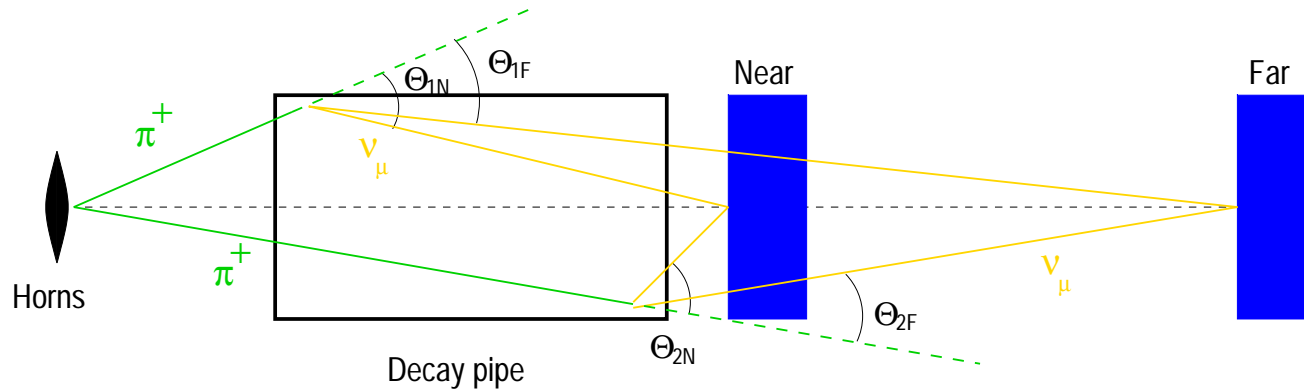
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- Everything is old and has been shown more than once.
  - This is mainly the idea, little has been really done (to my best knowledge).

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# The idea of a correlation matrix

When  $\Theta_N \neq \Theta_F$ :



- The same parent pion beam strongly correlates the Near and Far spectra, but  $E_{Far} \neq E_{Near}$ .
- Each neutrino observed in the near detector  $\equiv$  expected certain flux of neutrinos in the far detector, with  $P(E_{Far}, E_{Near}) \neq \delta(E_{Near})$ :

$$\frac{dN_{Far}}{dE_{Far}} = \int P(E_{Far}, E_{Near}) \frac{dN_{Near}}{dE_{Near}} dE_{Near}.$$

- $P(E_{Far}, E_{Near})$  determined primarily by beamline geometry (and location of the far detector).

# The idea of a correlation matrix II

## How to get $P(E_{Far}, E_{Near})$

- Every decaying pion is assigned to weights:  $w_{Near/Far} = w_{Near/Far}(E_\pi, \Theta_\pi, z, r)$ , defined as the fraction of all decays with a neutrino ending up in the near/far detector.
- Neutrino energies  $E_{Near/Far}$  are unambiguously given by  $E_\pi, \Theta_\pi, z, r$ , assuming point-like detectors (good approximation for NuMI).
- For a given pion decay, every neutrino with  $E_{Near}$  implies  $w_{Far}/w_{Near}$  neutrinos with  $E_{Far}$ .
- For a non-trivial, known, pion decay distribution  $\Phi_\pi(E_\pi, \Theta_\pi, z, r)$ :

$$P(E_{Far}, E_{Near}) = \frac{\int \int \int \int \Phi_\pi w_{Far} dE_\pi d\Theta_\pi dz dr}{\int \int \int \int \Phi_\pi w_{Near} dE_\pi d\Theta_\pi dz dr}$$

with integration over all phase space yielding  $E_{Near}$  and  $E_{Far}$  in the numerator, and  $E_{Near}$  in the denominator.

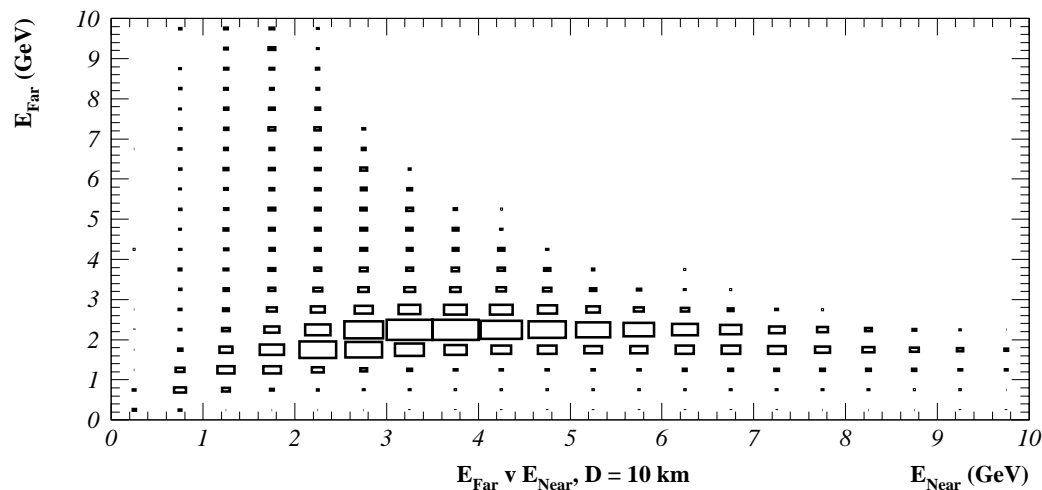
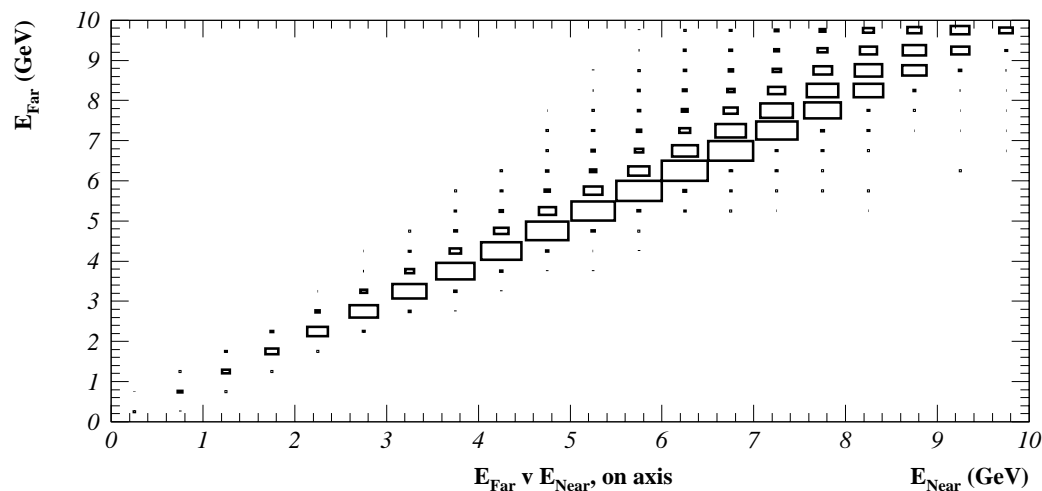
# The idea of a correlation matrix

- Far spectrum prediction in finite energy bins:

$$P(E_{Far}, E_{Near}) \rightarrow M(N_{bins} \times N_{bins}).$$

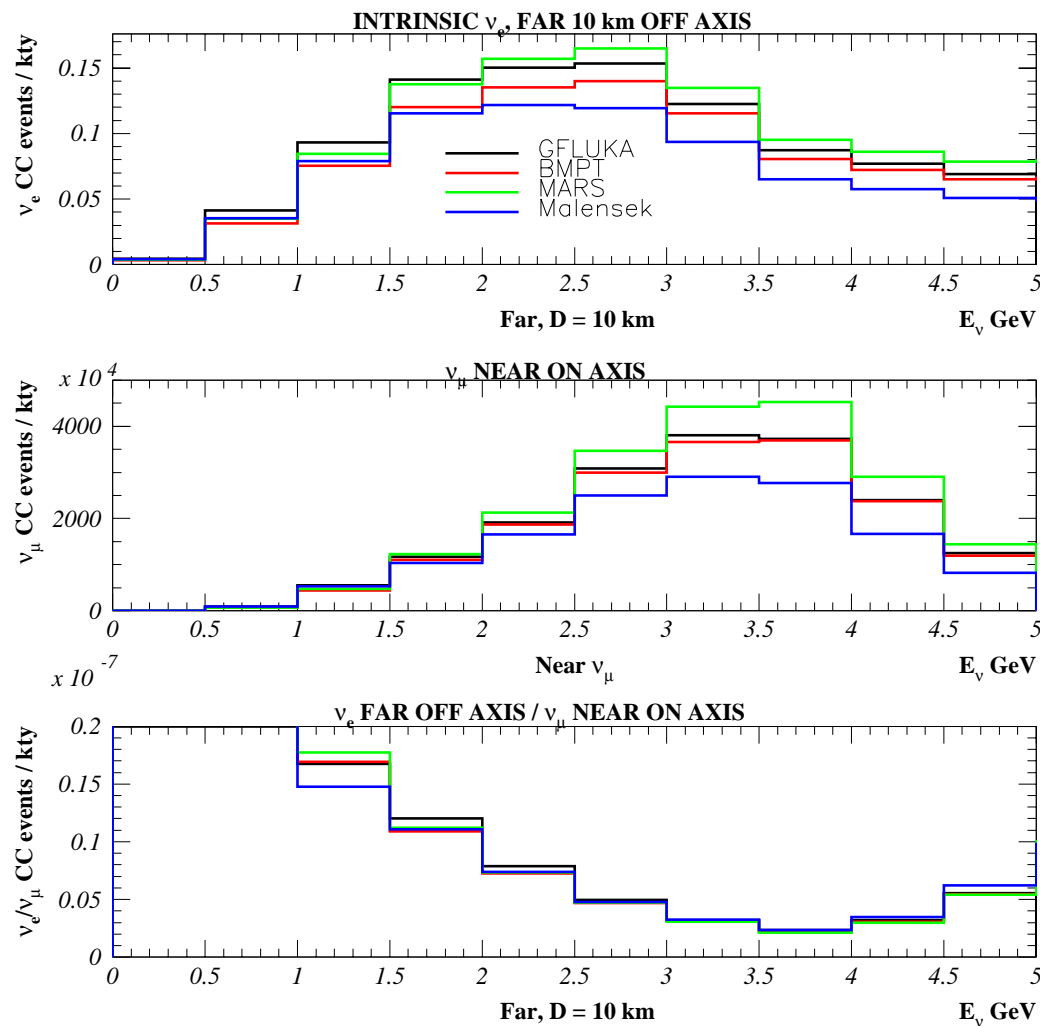
$$\begin{matrix} \rightarrow & \rightarrow \\ N_{Far} = M \cdot N_{Near} \end{matrix}$$

$M$  - Near-to-far correlation matrix, constructed from correlated  $(E_{Near}, E_{Far})$  pairs; in general non-diagonal.



# Off-axis experiment - $\nu_e$ background

- Hadron production related uncertainties in evaluating the intrinsic  $\nu_e$  component of the beam are minimized by using  $\nu_\mu$  information from the on-axis near detector.
- In the same pion beam, the number of intrinsic  $\nu_e$  is strongly correlated to the number of  $\nu_\mu$  measured in the near detector.



## Off-axis experiment - $\nu_e$ background II

- Optimization of the prediction is done by appropriately choosing the energy range of  $\nu_\mu$ , such that they come from as much as possible from **the same pions** as the  $\nu_e$  in the signal region.
- A simple ratio of events  $(\nu_e \text{ Far Off-axis})/(\nu_\mu \text{ Near On-axis})$ , both integrated within  $1 < E_\nu < 3 \text{ GeV}$ , is constant within  **$\sim 6\%$**  (for LE and assuming pion decays only).
- For the ME option, a similar result may be obtained by looking at the number of  $\nu_\mu$  Near On-axis within 3-8 GeV.
- Kaon decays contribute less than 10% to  $\nu_\mu$  in the near detector in this energy region, therefore correlations may decrease by 10%  $\rightarrow$  6% may become 6.6%. Other contributions are negligible.
- **Improvements possible:** next page.

## Off-axis experiment - $\nu_e$ background III

1. In an analogous way to the Near-to-Far correlation matrix for  $\nu_\mu$ 's, a **Near- $\nu_\mu$ -to-far- $\nu_e$**  correlation matrix can be computed  $\rightarrow$  possibly a more accurate  $\nu_e$  prediction than from a simple ratio,
2. Can also correlate **far- $\nu_e$**  to **near- $\bar{\nu}_\mu$** . These are more strongly correlated, as coming from the same **muon** decays. Both methods may be a valuable cross check of each other.

If so simple, why not done yet?

- Standard GNuMI ntuples (produced by J.Hylen and G.Unel) contain a record of only one neutrino type per event  $\rightarrow \nu_\mu, \bar{\nu}_\mu$  and  $\nu_e$  events are not correlated!
- Need to change the standard GNuMI ntuple format such that all neutrinos in an event are recorded (if more than one), in order to compute the appropriate correlation matrices. Then, generation of a huge statistics is required and creation of new ntuples.